

- 1 -

1 Electron-Emitting Device and Method of Manufacturing
 the Same as Well as Electron Source and
 Image-Forming Apparatus

5 BACKGROUND OF THE INVENTION

Field of the Invention

 This invention relates to an electron source
 and an image-forming apparatus such as a display
 apparatus incorporating an electron source and, more
10 particularly, it relates to a novel surface conduction
 electron-emitting device as well as a novel electron
 source and an image-forming apparatus such as a display
 apparatus incorporating such an electron source.

Related Background Art

15 There have been known two types of electron-
 emitting device; the thermoelectron type and the cold
 cathode type. Of these, the cold cathode type include
 the field emission type (hereinafter referred to as
 the FE-type), the metal/insulation layer/metal type
20 (hereinafter referred to as the MIM-type) and the
 surface conduction type.

 Examples of the FE electron-emitting device are
 described in W. P. Dyke & W. W. Dolan, "Field emission",
 Advance in Electron Physics, 8, 89 (1956) and C. A.
25 Spindt, "PHYSICAL Properties of thin-film field emission
 cathodes with molybdenum cones", J. Appl. Phys., 47,
 5284 (1976).

1 MIM devices are disclosed in papers including
C. A. Mead, "The tunnel-emission amplifier", J. Appl.
Phys., 32, 646 (1961). Surface-conduction electron-
emitting devices are proposed in papers including M. I.
5 Elinson, Radio Eng. Electron Phys., 10 (1965).

 An SCE device is realized by utilizing the
phenomenon that electrons are emitted out of a small
thin film formed on a substrate when an electric current
is forced to flow in parallel with the film surface.
10 While Elinson proposes the use of SnO_2 thin film for a
device of this type, the use of Au thin film is proposed
in [G. Dittmer: "Thin Solid Films", 9, 317 (1972)]
whereas the use of $\text{In}_2\text{O}_3/\text{SnO}_2$ and that of carbon thin
film are discussed respectively in [M. Hartwell and C. G.
15 Fonstad: "IEEE Trans. ED Conf.", 519 (1975)] and [H.
Araki et al.: "Vacuum", Vol. 26, No. 1, p. 22 (1983)].

 Fig. 27 of the accompanying drawings schematically
illustrates a typical surface-conduction electron-
emitting device proposed by M. Hartwell. In Fig. 27,
20 reference numeral 1 denotes a substrate. Reference
numeral 2 denotes an electrically conductive thin film
normally prepared by producing an H-shaped thin metal
oxide film by means of sputtering, part of which
eventually makes an electron-emitting region 3 when it
25 is subjected to an electrically energizing process
referred to as "electric forming" as described
hereinafter. In Fig. 27, the thin horizontal area of

1 the metal oxide film separating a pair of device
electrodes has a length L of 0.5 to 1 mm and a width W
of 0.1 mm. Note that the electron-emitting region 3
is only ~~very~~ schematically shown because there is no
5 way to accurately know its location and contour.

As described above, the conductive film 2 of
such a surface conduction electron-emitting device is
normally subjected to an electrically energizing
preliminary process, which is referred to as "electric
10 forming", to produce an electron emitting region 3.
In the electric forming process, a DC voltage or a
slowly rising voltage that rises typically at a rate of
1 V/min. is applied to given opposite ends of the
conductive film 2 to partly destroy, deform or transform
15 the thin film and produce an electron-emitting region 3
which is electrically highly resistive. Thus, the
electron-emitting region 3 is part of the conductive
film 2 that typically contains fissures therein so that
electrons may be emitted from those fissures. The thin
20 film 2 containing an electron-emitting region that has
been prepared by electric forming is hereinafter
referred to as a thin film 4 inclusive of an electron-
emitting region. Note that, once subjected to an
electric forming process, a surface conduction electron-
25 emitting device comes to emit electrons from its electron-
emitting region 3 whenever an appropriate voltage is
applied to the thin film 4 inclusive of the

1 electron-emitting region to make an electric current run
through the device.

Known surface conduction electron-emitting
devices having a configuration as described above are
5 accompanied by various problems, which will be
described hereinafter.

Since a surface conduction electron-emitting
device as described above is structurally simple and
can be manufactured in a simple manner, a large number
10 of such devices can advantageously be arranged on a
large area without difficulty. As a matter of fact, a
number of studies have been made to fully exploit this
advantage of surface conduction electron-emitting
devices. Applications of devices of the type under
15 consideration include charged electron beam sources
and electronic displays. In typical examples of
applications involving a large number of surface
conduction electron-emitting devices, the devices are
arranged in parallel rows to show a ladder-like shape
20 and each of the devices are respectively connected at
given opposite ends with wirings (common wirings) that
are arranged in columns to form an electron source (as
disclosed in Japanese Patent Application Laid-open
Nos. 64-31332, 1-283749 and 1-257552). As for display
25 apparatuses and other image-forming apparatuses
comprising surface conduction electron-emitting devices
such as electronic displays, although flat-panel type

1 displays comprising a liquid crystal panel in place of
a CRT have gained popularity in recent years, such
displays are not without problems. One of the problems
is that a light source needs to be additionally
5 incorporated into the display in order to illuminate
the liquid crystal panel because the display is not of
the so-called emission type and, therefore, the
development of emission type display apparatuses has
been eagerly expected in the industry. An emission type
10 electronic display that is free from this problem can be
realized by using a light source prepared by arranging
a large number of surface conduction electron-emitting
devices in combination with fluorescent bodies that are
made to shed visible light by electrons emitted from
15 the electron source (See, for example, United States
Patent No. 5,066,883).

In a conventional light source comprising a
large number of surface conduction electron-emitting
devices arranged in the form of a matrix, devices are
20 selected for electron emission and subsequent light
emission of fluorescent bodies by applying drive signals
to appropriate row-directed wirings connecting respective
rows of surface conduction electron-emitting devices in
parallel, column-directed wirings connecting respective
25 columns of surface conduction electron-emitting devices
in parallel and control electrodes (or grids arranged
within a space separating the electron source and the

1 fluorescent bodies along the direction of the columns
of surface conduction electron-emitting devices of a
direction perpendicular to that of the rows of devices
(See, for example, Japanese Patent Application Laid-open
5 No. 1-283749).

However, little has been known about the
behavior in vacuum of a surface conduction electron-
emitting device to be used for an electron source and an
image-forming apparatus incorporating such an electron
10 source and, therefore, it has been desired to provide
surface conduction electron-emitting devices that have
stable electron-emitting characteristics and hence can
be operated efficiently in a controlled manner. The
efficiency of a surface conduction electron-emitting
15 device is defined for the purpose of the present
invention as the ratio of the electric current running
between the pair of device electrodes of the device
(hereinafter referred to device current I_f) to the
electric current produced by the emission of electrons
20 into vacuum (hereinafter referred to emission current I_e).
It is desired to have a large emission current with a
small device current.

The inventors of the present invention who have
long been engaged in the study of this technological
25 field strongly believe that contaminants excessively
deposited on and near the electron-emitting region of a
surface conduction electron-emitting device can

1 deteriorate the performance of the device, that
contaminants are mainly decomposition products of oil
in the evacuation system used for the device and that
such deterioration can be prevented if the electron-
5 emitting region is controlled in terms of shape,
material and composition.

Thus, a low electricity consuming high quality
image-forming apparatus typically comprising an image-
forming member of fluorescent bodies can be realized if
10 there provided a surface conduction electron-emitting
device that has stable electron-emitting characteristics
and hence can be operated efficiently in a controlled
manner. Such an improved image-forming apparatus may be
a very flat television set. A low energy consuming
15 image-forming apparatus may require less costly drive
circuits and other related components.

SUMMARY OF THE INVENTION

In view of the above described circumstances, it
20 is therefore an object of the present invention to
provide a novel and highly efficient electron-emitting
device that has stable electron-emitting characteristics
with a low device current level and a high emission
current and hence can be operated efficiently in a
25 controlled manner and a novel method of manufacturing
the same well as a novel electron source incorporating
such an electron-emitting and an image-forming apparatus

1 such as a display apparatus using such an electron
source.

 According to an aspect of the invention, the
above object and other objects of the invention are
5 achieved by providing an electron-emitting device
comprising a pair of oppositely disposed electrodes and
an electroconductive film arranged between the electrodes
and including a high resistance region, characterized in
that the high resistance region has a deposit containing
10 carbon as a principal ingredient.

 According to another aspect of the invention,
there is provided a method of manufacturing an electron-
emitting device comprising a pair of oppositely disposed
electrodes and an electroconductive film arranged
15 between the electrodes and including a high resistance
region, characterized in that it comprises a step of
activating the device.

 According to still another aspect of the invention,
there is provided an electron source comprising an
20 electron-emitting device for emitting electrons as a
function of input signals characterized in that said
electron-emitting device is produced with the above
described method.

 According to a further aspect of the invention,
25 there is provided an image-forming apparatus comprising
an electron source and an image-forming member for
forming images as a function of input signals

1 characterized in that said electron source comprises
an electron-emitting device that is produced with the
above described method.

Now, the present invention will be described
5 in greater detail by referring to the accompanying
drawings that illustrate preferred embodiments of the
invention.

BRIEF DESCRIPTION OF THE DRAWINGS

10 Figs. 1A and 1B are schematic plan and
sectional side views showing the basic configuration of
a flat type surface conduction electron-emitting device
according to the invention.

Figs. 2A through 2C are schematic side views
15 showing different steps of a method of manufacturing a
surface conduction electron-emitting device according to
the invention.

Fig. 3 is a block diagram of a gauging system for
determining the performance of a surface-conduction type
20 electron-emitting device according to the invention.

Figs. 4A through 4C are graphs showing voltage
waveforms observed during an electrically energizing
process conducted on a surface conduction electron-
emitting device according to the invention.

25 Fig. 5 is a graph showing the relationship
between the device current and the time of activation
process.

1 Figs. 6A and 6B are schematic sectional views
showing an embodiment of surface conduction electron-
emitting device according to the invention before and
after an activation process respectively.

5 Fig. 7 is a graph showing the relationship
between the device voltage and the device current as
well as the relationship between the device voltage and
the emission current of an embodiment of surface
conduction electron-emitting device according to the
10 invention.

Fig. 8 is a schematic plan view of the substrate
of an embodiment of electron source according to the
invention used in Example 2 as described hereinafter,
showing in particular the simple matrix configuration of
15 the substrate.

Fig. 9 is a schematic perspective view of the
substrate of the embodiment of electron source of Fig. 8.

Figs. 10A and 10B are enlarged schematic plan
views of two different fluorescent layers that can be
20 used alternatively for the embodiment of Fig. 8.

Fig. 11 is a plan view of the electron source
used in Example 1 as described hereinafter.

Fig. 12 is a block diagram of the system used for
the activation process of Example 3 as described
25 hereinafter.

Fig. 13 is an enlarged schematic partial plan
view of the substrate of the electron source of an

1 embodiment of image-forming apparatus according to the
invention used in Example 2 as described hereinafter.

Fig. 14 is an enlarged schematic sectional side
view of the substrate of Fig. 13 taken along line A-A'.

5 Figs. 15A through 15D and 16E through 16H are
schematic partial sectional side views of the substrate
of Fig. 13, showing different steps of the method of
manufacturing the same.

Figs. 17 and 18 are schematic plan views of two
10 different substrates of electron source alternatively
used in the image-forming apparatus of Example 9.

Figs. 19 and 22 are schematic perspective views
of two different panels alternatively used in the image-
forming apparatus of Example 9.

15 Figs. 20 and 23 are block diagrams of two
different electric circuits alternatively used to drive
the image-forming apparatus of Example 9.

Figs. 21A through 21F and 24A through 24I are
two different sets of timing charts alternatively used
20 to drive the image-forming apparatus of Example 9.

Fig. 25 is a block diagram of the display
apparatus of Example 10.

Fig. 26 is a schematic side view of an embodiment
of step type surface conduction electron-emitting
25 device according to the invention.

Fig. 27 is a schematic plan view of a conventional
surface conduction electron-emitting device.

1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, the present invention will be described in terms of preferred embodiments of the invention.

The present invention relates to a novel surface
5 conduction electron-emitting device, a method of manufacturing the same and a novel electron source incorporation such a device as well as an image-forming apparatus such as a display apparatus incorporating such an electron source and applications of such an apparatus.

10 A surface conduction electron-emitting device according to the invention may be realized either as a flat type or as a step type. Firstly, a flat type surface conduction electron-emitting device will be described.

15 Figs. 1A and 1B are schematic plan and sectional side views showing the basic configuration of a flat type surface conduction electron-emitting device according to the invention.

Referring to Figs. 1A and 1B, the device
20 comprises a substrate 1, a pair of device electrodes 5 and 6, a thin film 4 including an electron-emitting region 3.

Materials that can be used for the substrate 1 include quartz glass, glass containing impurities such
25 as Na to a reduced concentration level, soda lime glass, glass substrate realized by forming an SiO_2 layer on soda lime glass by means of sputtering, ceramic

1 substances such as alumina.

While the oppositely arranged device electrodes
5 and 6 may be made of any highly conducting material,
preferred candidate materials include metals such as Ni,
5 Cr, Au, Mo, W, Pt, Ti, Al, Cu and Pd and their alloys,
printable conducting materials made of a metal or a
metal oxide selected from Pd, Ag, RuO_2 , Pd-Ag and glass,
transparent conducting materials such as In_2O_3 - SnO_2 and
semiconductor materials such as poly-silicon.

10 The distance L_1 separating the device electrodes,
the length W_1 of the device electrodes, the contour of
the electroconductive film 4 and other factors for
designing a surface conduction electron-emitting device
according to the invention may be determined depending
15 on the application of the device. If, for instance,
it is used for an image-forming apparatus such as a
television set, it may have to have dimensions
corresponding to those of each pixel that may be very
small if the television set is of a high definition
20 type, although it is required to provide a satisfactory
emission current in order to ensure sufficient brightness
for the screen of the television set while meeting the
rigorous dimensional requirements.

The distance L_1 separating the device electrodes
25 5 and 6 is preferably between hundreds nanometers and
hundreds micrometers and, still preferably, between
several micrometers and tens of several micrometers.

1 depending on the voltage to be applied to the device
electrodes and the field strength available for
electron emission.

The length W_1 of the device electrodes 5 and 6
5 is preferably between several micrometers and hundreds
of several micrometers depending on the resistance of
the electrodes and the electron-emitting characteristics
of the device. The film thickness d of the device
electrodes 5 and 6 is between tens of several
10 nanometers and several micrometers.

A surface conduction electron-emitting device
according to the invention may have a configuration
other than the one illustrated in Figs. 1A and 1B and,
alternatively, it may be prepared by laying a thin film
15 4 including an electron-emitting region on a substrate 1
and then a pair of oppositely disposed device electrodes
5 and 6 on the thin film.

The electroconductive thin film 4 is preferably
a fine particle film in order to provide excellent
20 electron-emitting characteristics. The thickness of the
electroconductive thin film 4 is determined as a function
of the stepped coverage of the thin film on the device
electrodes 5 and 6, the electric resistance between the
device electrodes 5 and 6 and the parameters for the
25 forming operation that will be described later as well
as other factors and preferably between a nanometer and
hundreds of several nanometers and more preferably

1 between a nanometer and fifty nanometers. The thin
film 4 normally shows a resistance per unit surface
area between 10^3 and $10^7 \Omega/\square$.

5 The thin film 4 including the electron-emitting
region is made of fine particles of a material selected
from metals such as Pd, Ru, Ag, Au, Ti, In, Cu, Cr, Fe,
Zn, Sn, Ta, W and Pb, oxides such as PdO, SnO_2 , In_2O_3 ,
PbO and Sb_2O_3 , borides such as HfB_2 , ZrB_2 , LaB_6 , CeB_6 ,
YB₄ and GdB₄, carbides such as TiC, ZrC, HfC, TaC, SiC and
10 WC, nitrides such as TiN, ZrN and HfN, semiconductors
such as Si and Ge and carbon.

The term "a fine particle film" as used herein
refers to a thin film constituted of a large number of
fine particles that may be loosely dispersed, tightly
15 arranged or mutually and randomly overlapping (to form
an island structure under certain conditions).

The diameter of fine particles to be used for
the purpose of the present invention is between a
nanometer and hundreds of several nanometers and
20 preferably between a nanometer and twenty nanometers.

The electron-emitting region is part of the
electroconductive thin film 4 and comprises electrically
highly resistive fissures, although it is dependent on
the thickness and the material of the electroconductive
25 thin film 4 and the electric forming process which will
be described hereinafter. It may contain electroconductive
fine particles having a diameter between several angstroms

1 and hundreds of several angstroms. The material of the
electron-emitting region 3 may be selected from all
or part of the materials that can be used to prepare
the thin film 4 including the electron-emitting region.
5 The thin film 4 contain carbon and/or carbon compounds
in the electron-emitting region 3 and its neighboring
areas.

A surface conduction type electron-emitting
device according to the invention and having an
10 alternative profile, or a step type surface conduction
electron-emitting device, will be described.

Fig. 26 is a schematic perspective view of a
step type surface conduction electron-emitting device,
showing its basic configuration.

15 As seen in Fig. 26, the device comprises a
substrate 1, a pair of device electrodes 265 and 266
and a thin film 264 including an electron-emitting
region 263, which are made of materials same as a flat
type surface conduction electron-emitting device as
20 described above, as well as a step-forming section 261
made of an insulating material such as SiO_2 produced by
vacuum deposition, printing or sputtering and having a
film thickness corresponding to the distance L_1
separating the device electrodes of a flat type surface
25 conduction electron-emitting device as described above,
or between tens of several nanometers and tens of
several micrometers and preferably between tens of

1 several nanometers and several micrometers, although
it is selected as a function of the method of producing
the step-forming section used there, the voltage to be
applied to the device electrodes and the field strength
5 available for electron emission.

As the thin film 264 including the electron-emitting region is formed after the device electrodes 265 and 266 and the step-forming section 261, it may preferably be laid on the device electrodes 265 and
10 266. While the electron-emitting region 263 is shown to have straight outlines in Fig. 26, its location and contour are dependent on the conditions under which it is prepared, electric forming conditions and other related conditions and not limited to straight
15 outlines.

While various methods may be conceivable for manufacturing an electron-emitting device including an electron-emitting region 3, Figs. 2A through 2C illustrate a typical one of such methods.

20 Now, a method of manufacturing a flat type surface conduction electron-emitting device according to the invention will be described by referring to Figs. 1A and 1B and 2A through 2C.

1) After thoroughly cleansing a substrate 1 with
25 detergent and pure water, a material is deposited on the substrate 1 by means of vacuum deposition, sputtering or some other appropriate technique for a pair of device

1 electrodes 5 and 6, which are then produced by
photolithography (Fig. 2A).

2) An organic metal thin film is formed on the
substrate 1 between the pair of device electrodes 5 and
5 6 by applying an organic metal solution and leaving the
applied solution for a given period of time. An
organic metal solution as used herein refers to a
solution of an organic compound containing as a
principal ingredient a metal selected from the group of
10 metals cited above including Pd, Ru, Ag, Au, Ti, In,
Cu, Cr, Fe, Zn, Sn, Ta, W and Pb. Thereafter, the
organic metal thin film is heated, sintered and
subsequently subjected to a patterning operation,
using an appropriate technique such as lift-off or
15 etching, to produce a thin film 2 for forming an
electron-emitting region (Fig. 2B). While an organic
metal solution is used to produce a thin film in the
above description, a thin film may alternatively be
formed by vacuum deposition, sputtering, chemical vapor
20 phase deposition, dispersed application, dipping, spinner
or some other technique.

3) Thereafter, the device electrodes 5 and 6
are subjected to an electrically energizing process
referred to as "forming", where a pulse voltage or a
25 rising voltage is applied to the device electrodes 5
and 6 from a power source (not shown) to produce an
electron-emitting region 3 in the thin film 2 forming

1 an electron-emitting region (Fig. 2C). The area of
the thin film 2 for forming an electron-emitting region
that has been locally destroyed, deformed or transformed
to undergo a structural change is referred to as an
5 electron-emitting region 3.

All the remaining steps of the electric
processing including the forming operation and the
activation operation to be conducted on the device
are carried out by using a gauging system which will be
10 described below by referring to Fig. 3.

Fig. 3 is a schematic block diagram of a gauging
system for determining the performance of an electron-
emitting device having a configuration as illustrated in
Figs. 1A and 1B. In Fig. 3, the device comprises a substrate
15 1, a pair of device electrodes 5 and 6, a thin film 4
including an electron-emitting region 3. Otherwise, the
gauging system comprises an ammeter 30 for metering the
device current I_f running through the thin film 4
including the electron-emitting region 3 between the
20 device electrodes 5 and 6, a power source 31 for
applying a device voltage V_f to the device, an anode
34 for capturing the emission current I_e emitted from the
electron-emitting region of the device, a high voltage
source 33 for applying a voltage to the anode 34 of the
25 gauging system and another ammeter 32 for metering the
emission current I_e emitted from the electron-emitting
region 3 of the device.

1 For measuring the device current I_f and the
emission current I_e , the device electrodes 5 and 6 are
connected to the power source 31 and the ammeter 30
and the anode 34 is placed above the device and
5 connected to the power source 33 by way of the ammeter
32. The electron-emitting device to be tested and the
anode 34 are put into a vacuum chamber, which is
provided with an exhaust pump, a vacuum gauge and other
pieces of equipment necessary to operate a vacuum
10 chamber so that the metering operation can be conducted
under a desired vacuum condition. The exhaust pump may
be provided with an ordinary high vacuum system
comprising a turbo pump or a rotary pump or an oil-free
high vacuum system comprising an oil-free pump such
15 as a magnetic levitation turbo pump or a dry pump and
an ultra-high vacuum system comprising an ion pump.

 The vacuum chamber of the gauging system is
connected to an ampoule or a gas bomb containing one or
more than one organic substances by way of a needle
20 valve so that the operation of activation may be
carried out in the vacuum chamber, feeding the organic
substances in gaseous form into the vacuum chamber.
The feed rate may be regulated by controlling the needle
valve and the exhaust pump, monitoring the degree of
25 vacuum in the chamber by means of a vacuum gauge.

 The vacuum chamber and the substrate of the
electron source can be heated to approximately 200°C by

1 means of a heater (not shown).

For determining the performance of the device,
a voltage between 1 and 10 KV is applied to the anode,
which is spaced apart from the electron-emitting
5 device by distance H which is between 2 and 8 mm.

For the forming operation, a constant pulse
voltage or aⁿ increasing pulse voltage may be applied.
The operation of using a constant pulse voltage will be
described first by referring to Fig. 4A, showing a
10 pulse voltage having a constant pulse height.

In Fig. 4A, the pulse voltage has a pulse
width T1 and a pulse interval T2, which are between 1
and 10 microseconds and between 10 and 100 milliseconds
respectively. The height of the triangular wave (the
15 peak voltage for the electric forming operation) may
be appropriately selected so long as the voltage is
applied in vacuum.

Fig. 4B shows a pulse voltage whose pulse
height increases with time. In Fig. 4B, the pulse
20 voltage has an width T1 and a pulse interval T2, which
are between 1 and 10 microseconds and between 10 and
100 milliseconds respectively. The height of the
triangular wave (the peak voltage for the electric
forming operation) is increased at a rate of, for
25 instance, 0.1 V per step in vacuum.

The electric forming operation will be terminated
when typically a resistance greater than 1 M ohms is

1 observed for the device current running through the
thin film 2 for forming an electron-emitting region
while applying a voltage of approximately 0.1 V is
applied to the device electrodes to locally destroy
5 or deform the thin film. The voltage observed when the
electric forming operation is terminated is referred to
as the forming voltage V_f .

While a triangular pulse voltage is applied to
the device electrodes to form an electron-emitting
10 region in an electric forming operation as described
above, the pulse voltage may have a different wave form
such as rectangular form and the pulse width and the
pulse interval may be of values other than those cited
above so long as they are selected as a function of
15 the device resistance and other values that meet the
requirements for forming an electron-emitting region.
Additionally, since the forming voltage is unequivocally
defined in terms of the material and the configuration
of the device and other related factors, it is
20 preferable to apply a pulse voltage having an
increasing wave height rather than to apply a pulse
voltage with a constant wave height because a desired
energy level may be easily selected for each device to
give rise to desired electron emission characteristics
25 for the device.

4) After the electric forming operation, the
device is subjected to an activation process, where a

1 pulse voltage having a constant wave height is
repeatedly applied to the device in vacuum of a
desired degree as in the case of the forming operation
so that carbon and/or carbon compounds may be deposited
5 on the device out of the organic substances existing in
the vacuum in order to cause the device current I_f and
the emission current I_e of the device to change
markedly (hereinafter referred to as activation
process). Organic substances can be supplied into
10 vacuum by arranging in the turbo pump or the rotary
pump containing the organic substances in such a way
that the organic substances are also held in vacuum or,
preferably, by feeding one or more than one predetermined
carbon compounds into the vacuum chamber containing the
15 device but not any oil. Carbon compounds to be fed into
the vacuum chamber are preferably organic substances.
The activation process is terminated when the emission
current I_e gets to a saturation point while gauging
the device current I_f and the emission current I_e . Fig.
20 5 typically shows how the device current I_f and the
emission current I_e are dependent on the duration of
the activation process. It should also be noted that,
in the activation process, the time dependency of the
device current I_f and the emission current I_e varies as
25 a function of the degree of vacuum and the pulse voltage
applied to the device and that the contour and the state
of the deformed or transformed portion of the thin film

1 depend on how the forming process is carried out. In
Fig. 5, the time dependency of the device current I_f
and the emission current I_e is illustrated for a
typical high resistance activation process and a typical
5 low resistance activation process. In either case, it
will be seen that the emission current I_e increases
with the duration of the activation process so that
the device may eventually reach a level of emission
current I_e required for its application.

10 Organic substances that can suitably be used
for the purpose of the invention show a vapor pressure
greater 0.2 hPa and smaller than 5,000 hPa and
preferably greater than 10 hPa and smaller than 5,000
hPa at temperature where they are effectively adsorbed
15 by the area 3 of the device that has been deformed or
transformed in the forming process.

The activation process is preferably conducted
at room temperature from the viewpoint of feeding
organic substances and controlling the temperature of
20 the device.

If the activation process is conducted at 20°C,
organic substances that can suitably be used for the
purpose of the invention needs to show a vapor pressure
greater than 0.2 hPa and smaller than 5,000 hPa.

25 Organic substances that can be used for the
purpose of the invention include aliphatic hydrocarbons
such as alkanes, alkenes and alkynes, aromatic

1 hydrocarbons, alcohols, aldehydes, ketones, amines and
organic acids such as phenylic acids, carbonic acids and
sulfonic acids as well as their derivatives that may
produce a required vapor pressure.

5 Some specific organic substances to be suitably
used for the purpose of the invention includes
butadiene, n-hexane, 1-hexane, benzene, toluene, o-
xylene, benzonitrile, chloroethylene, trichloroethylene,
methanol, ethanol, isopropyl alcohol, formaldehyde,
10 acetaldehyde, propanol, acetone, ethyl methyl ketone,
diethyl ketone, methyl amine, ethyl amine, ethylene
diamine, phenol, formic acid, acetic acid and propionic
acid.

 The activation process may become excessively
15 time consuming and not practical for an electron-emitting
device according to the invention, if the vapor pressure
of organic substances exceeds 5,000 hPa at 20°C in the
vacuum chamber.

 If, on the other hand, the vapor pressure of
20 organic substances in the vacuum chamber falls under
0.2 hPa at 20°C in the vacuum chamber, the operation of
depositing additional carbon and/or carbon compounds in
Step 5) described below becomes impracticable and the
device current I_f and the emission current I_e may have
25 difficulty to get to a constant level. If such is the
case, the emission current may become variable as the
pulse width of the drive voltage for driving the device

1 changes (a phenomenon to be referred to pulse width
dependency hereinafter). This phenomenon may be
attributable to the adsorption residue of the organic
substances such as ingredients of oil left on an area
5 in and near the electron-emitting region of the device
that becomes hardly removable after the activation
process. Once such a phenomenon becomes existent, so-
called pulse modulation or the technique of controlling
the rate of electron emission of an electron-emitting
10 device by controlling the pulse width of the pulse
voltage applied to the device and hence gradated
display of images on a display medium comprising
electron-emitting devices arranged in the form of
simple matrix (as will described hereinafter) will not
15 be feasible any longer.

If, additionally, a large number of electron-
emitting devices are arranged in a narrow space as
in the case of a flat type display panel as will be
described hereinafter, highly adsorbable organic
20 substances such as ingredients of oil to be used for
activation can hardly be distributed evenly within the
narrow space nor removed after the activation process
so that the pulse-width dependency of the devices may be
adversely affected.

25 For the above described reasons, the vapor
pressure of the organic substances in the activation
process is preferably between 0.2 hPa and 5,000 hPa at

1 20°C.

The feeding partial pressure of the organic substances is preferably between 10^{-2} and 10^{-7} torr when an ordinary exhaust device is used.

5 Assuming that the vapor pressure of the organic substances is P_{r0} and the feeding partial pressure is P_r , the feeding partial pressure P_r is preferably greater than $P_{r0} \times 10^{-8}$ and determined as a function of the organic substances involved.

10 If the feeding partial pressure of the organic substances is lower than the above level, the activation process may become excessively time consuming and not practical for an electron-emitting device according to the invention.

15 The activation process is referred to as a high resistance activation process when the pulse voltage used in the process is sufficiently high relative to the forming voltage V_{form} , whereas it is referred to as a low resistance activation process
20 when the pulse voltage used in the process is sufficiently low relative to the forming voltage V_{form} . More specifically, the initial voltage V_p that indicates the voltage controlled negative resistance of the device as defined hereinafter provides a reference for
25 the above distinction. Note that electron-emitting devices activated by a high resistance activation process are preferable than those activated by a low

1 resistance activation process from the viewpoint of
performance. More specifically, the activation process
is preferably conducted on an electron-emitting device
according to the invention with the operating voltage
5 of the device.

Figs. 6A and 6B schematically illustrate how
an electron-emitting device according to the invention
is treated in the high and low resistance activation
processes when observed through an FESEM or TEM. Figs.
10 6A and 6B respectively show schematic cross sectional
views of a device treated by a high resistance
activation process and a low resistance activation
process. In a high resistance activation process
(Fig. 6A), carbon and/or carbon compounds are remarkably
15 deposited on the high potential side of the device
partly beyond the area 3 deformed or transformed by
electric forming, whereas they are only slightly
deposited on the low potential side of the device.
When observed through a microscope having large
20 magnifying power, a deposit of carbon and/or carbon
compounds is found on and near some of the fine particles
of the device and, in some cases, even on the device
electrodes if the electrodes are located relatively
close to each other. The thickness of the film deposit
25 is preferably less than 500 angstroms and more
preferably less than 3,000 angstroms.

When observed through a TEM or Roman microscope,

1 it is found that the deposited carbon and/or carbon
compounds are mostly graphite (both mono- and poly-
crystalline) and non-crystalline carbon (or a mixture
of non-crystalline carbon and poly-crystalline
5 graphite).

In a low resistance activation process (Fig. 6B),
on the other hand, a deposit of carbon and/or carbon
compounds is found only in the area 3 that has been
deformed or transformed by electric forming. When
10 observed through a microscope having large magnifying
power, a deposit of carbon and/or carbon compounds is
also found on and near some of the fine particles of
the device.

Fig. 5 shows that a low resistance activation
15 process makes both the device and emission currents of
a device according to the invention higher than a high
resistance activation process.

5) An electron-emitting device that has been
treated in an electric forming process and an activation
20 process is then driven to operate in a vacuum of a
degree higher than that of the activation process.
Here, a vacuum of a degree higher than that of the
activation process means a vacuum of a degree greater
than 10^{-6} and, preferably, an ultra-high vacuum where
25 no carbon nor carbon compounds cannot be additionally
deposited on the device.

Thus, no carbon nor carbon compounds would be

1 deposited thereafter to establish stable device and
emission currents I_f and I_e .

Now, some of the basic features of an electron-
emitting device according to the invention and prepared
5 in the above described manner will be described below
by referring to Fig. 7.

Fig. 7 shows a graph schematically illustrating
the relationship between the device voltage V_f and the
emission current I_e and the device current I_f typically
10 observed by the gauging system of Fig. 3. Note that
different units are arbitrarily selected for I_e and I_f
in Fig. 7 in view of the fact that I_e has a magnitude by
far smaller than that of I_f . As seen in Fig. 7, an
electron-emitting device according to the invention
15 has three remarkable features in terms of emission
current I_e , which will be described below.

Firstly, an electron-emitting device according
to the invention shows a sudden and sharp increase in
the emission current I_e when the voltage applied thereto
20 exceeds a certain level (which is referred to as a
threshold voltage hereinafter and indicated by V_{th} in
Fig. 7), whereas the emission current I_e is practically
undetectable when the applied voltage is found lower
than the threshold value V_{th} . Differently stated, an
25 electron-emitting device according to the invention is a
non-linear device having a clear threshold voltage V_{th}
to the emission current I_e .

1 Secondly, since the emission current I_e is
highly dependent on the device voltage V_f , the former
can be effectively controlled by way of the latter.

 Thirdly, the emitted electric charge captured
5 by the anode 34 is a function of the duration of time
of application of the device voltage V_f . In other
words, the amount of electric charge captured by the
anode 34 can be effectively controlled by way of the
time during which the device voltage V_f is applied.

10 Because of the above remarkable features, it
will be understood that the electron-emitting behavior
of an electron source comprising a plurality of electron-
emitting devices according to the invention and hence
that of an image-forming apparatus incorporating such
15 an electron source can easily be controlled in response
to the input signal. Thus, such an electron source
and an image-forming apparatus may find a variety of
applications.

 On the other hand, the device current I_f either
20 monotonically increases relative to the device voltage
 V_f (as shown by a solid line in Fig. 7, a characteristic
referred to as MI characteristic hereinafter) or
changes to show a form specific to a voltage-controlled-
negative-resistance characteristic (as shown by a broken
25 line in Fig. 5, a characteristic referred to as VCNR
characteristic hereinafter). These characteristics
of the device current are dependent on a number of

1 factors including the manufacturing method, the conditions
where it is gauged and the environment for operating the
device. The critical voltage for the VCNR characteristic
to become apparent is referred to as the boundary voltage
5 VP.

Thus, it has been discovered that the VCNR
characteristic of the device current I_f varies remarkably
as a function of a number of factors including the
electric conditions of the electric forming process,
10 the vacuum conditions of the vacuum system, the vacuum
and electric conditions of the gauging system
particularly when the performance of the electron-
emitting device is gauged in the vacuum gauging system
after the electric forming process (e.g., the sweep
15 rate at which the voltage being applied to the electron-
emitting device is swept from low to high in order to
determine the current-voltage characteristic of the
device) and the duration of time for the electron-
emitting device to have been left in the vacuum system
20 before the gauging operation, although the device
current of the electron-emitting device never loses
the above identified three features.

Now, an electron source according to the
invention will be described.

25 An electron source and hence an image-forming
apparatus can be realized by arranging a plurality of
electron-emitting devices according to the invention

1 on a substrate. Electron-emitting devices may be
arranged on a substrate in a number of different modes.
For instance, a number of surface conduction electron-
emitting devices as described earlier by referring to
5 a light source may be arranged in rows along a direction
(hereinafter referred to row-direction), each device
being connected by wirings at opposite ends thereof,
and driven to operate by control electrodes (hereinafter
referred to as grids or modulation means) arranged in
10 a space above the electron-emitting devices along a
direction perpendicular to the row direction (hereinafter
referred to as column-direction), or, alternatively as
described below, a total of m X-directional wiring and
a total of n Y-directional wirings are arranged with
15 an interlayer insulation layer disposed between the X-
directional wirings and the Y-directional wiring along
with a number of surface conduction electron-emitting
devices such that the pair of device electrodes of each
surface conduction electron-emitting device are
20 connected respectively to one of the X-directional
wiring and one of the Y-directional wirings. The
latter arrangement is referred to as a simple matrix
arrangement. Now, the simple matrix arrangement will
be described in detail.

25 In view of the three basic features of a
surface conduction electron-emitting device according
to the invention, each of the surface conduction

1 electron-emitting devices having a simple matrix
arrangement configuration can be controlled for
electron emission by controlling the wave height and
the pulse width of the pulse voltage applied to the
5 opposite electrodes of the device above the threshold
voltage level. On the other hand, the device does not
emit any electron₁ below the threshold voltage level.
Therefore, regardless of the number of electron-
emitting devices, desired surface conduction electron-
10 emitting devices can be selected and controlled for
electron emission in response to the input signal by
applying a pulse voltage to each of the selected
devices.

Fig. 8 is a schematic plan view of the substrate
15 of an electron source according to the invention
realized by using the above feature. In Fig. 8, the
electron source comprises a substrate 81, X-directional
wirings 82, Y-directional wirings 83, surface conduction
electron-emitting devices 84 and connecting wires 85.
20 The surface conduction electron-emitting devices may
be either of the flat type or of the step type.

In Fig. 8, the substrate 81 of the electron
source may be a glass substrate and the number and
configuration of the surface conduction electron-
25 emitting devices arranged on the substrate may be
appropriately determined depending on the application
of the electron source.

1 There are provided a total of m X-directional
wirings 82, which are donated by DX_1, DX_2, \dots, DX_m
and made of a conductive metal formed by vacuum
deposition, printing or sputtering. These wirings are
5 so designed in terms of material, thickness and width
that, if necessary, a substantially equal voltage may
be applied to the surface conduction electron-emitting
devices. A total of n Y-directional wirings are
arranged and donated by DY_1, DY_2, \dots, DY_n , which are
10 similar to the X-directional wirings in terms of
material, thickness and width. An interlayer
insulation layer (not shown) is disposed between the
 m X-directional wirings and the n Y-directional wirings
to electrically isolate them from each other, the m
15 X-directional wirings and n Y-directional wirings
forming a matrix. (m and n are integers.)

 The interlayer insulation layer (not shown) is
typically made of SiO_2 and formed on the entire surface
or part of the surface of the insulating substrate 81
20 to show a desired contour by means of vacuum deposition,
printing or sputtering. The thickness, material and
manufacturing method of the interlayer insulation
layer are so selected as to make it withstand any
potential difference between an X-directional wiring
25 82 and a Y-directional wiring 83 at the crossing
thereof. Each of the X-directional wirings 82 and
the Y-directional wirings 83 is drawn out to form an

1 external terminal.

The oppositely arranged electrodes (not shown) of each of the surface conduction electron-emitting devices 84 are connected to the related one of the m X-directional wirings 82 and the related one of the n Y-directional wirings 83 by respective connecting wires 85 which are made of a conductive metal and formed by vacuum deposition, printing or sputtering.

The electroconductive metal material of the device electrodes and that of the connecting wires 85 extending from the m X-directional wirings 82 and the n Y-directional wirings 83 may be same or contain common elements as ingredients, the latter being appropriately selected depending on the former. If the device electrodes and the connecting wires are made of a same material, they may be collectively called device electrodes without discriminating the connecting wires. The surface conduction electron-emitting devices may be arranged directly on the substrate 81 or on the interlayer insulation layer (not shown).

The X-directional wirings 82 are electrically connected to a scan signal generating means (not shown) for applying a scan signal to a selected row of surface conduction electron-emitting devices 84 and scanning the selected row according to an input signal.

On the other hand, the Y-directional wirings

1 83 are electrically connected to a modulation signal
generating means (not shown) for applying a modulation
signal to a selected column of surface conduction
electron-emitting devices 84 and modulating the selected
5 column according to an input signal.

Note that the drive signal to be applied to
each surface conduction electron-emitting device is
expressed as the voltage difference of the scan signal
and the modulation signal applied to the device.

10 Now, an image-forming apparatus according to
the invention and comprising an electron source having
a simple matrix arrangement as described above will be
described by referring to Fig. 9 and Figs. 10A and 10B.
This apparatus may be a display apparatus. Referring
15 firstly to Fig. 9 illustrating the basic configuration
of the display panel of the image-forming apparatus,
it comprises an electron source substrate 81 of the
above described type, a rear plate 91 rigidly holding
the electron source substrate 81, a face plate 96
20 produced by laying a fluorescent film 94 and a metal
back 95 on the inner surface of a glass substrate 93
and a support frame 92. An enclosure 98 is formed
for the apparatus as frit glass is applied to said rear
plate 91, said support frame 92 and said face plate
25 96, which are subsequently baked to 400 to 500°C in
the atmosphere or in nitrogen and bonded together.

In Fig. 9, reference numeral 84 denotes the

1 electron-emitting region of each electron-emitting
device and reference numerals 82 and 83 respectively
denotes the X-directional wiring and the Y-directional
wiring connected to the respective device electrodes
5 of each electron-emitting device.

While the enclosure 98 is formed of the face
plate 96, the support frame 92 and the rear plate 91
in the above described embodiment, the rear plate 91
may be omitted if the substrate 81 is strong enough
10 by itself. If such is the case, an independent rear
plate 91 may not be required and the substrate 81 may
be directly bonded to the support frame 92 so that the
enclosure 98 is constituted of a face plate 96, a
support frame 92 and a substrate 81. The overall
15 strength of the enclosure 98 may be increased by
arranging a number of support members called spacers
(not shown) between the face plate 96 and the rear
plate 91.

Figs. 10A and 10B schematically illustrate two
20 possible arrangements of fluorescent bodies to form a
fluorescent film 94. While the fluorescent film 94
comprises only fluorescent bodies if the display panel
is used for showing black and white pictures, it needs
to comprises for displaying color pictures black
25 conductive members 101 and fluorescent bodies 102, of
which the former are referred to as black stripes or
members of a black matrix depending on the arrangement

1 of the fluorescent bodies. Black stripes or members
of a black matrix are arranged for a color display panel
so that the fluorescent bodies 102 of three different
primary colors are made less discriminable and the
5 adverse effect of reducing the contrast of displayed
images of external light is weakened by blackening
the surrounding areas. While graphite is normally
used as a principal ingredient of the black stripes,
other conductive material having low light transmissivity
10 and reflectivity may alternatively be used.

A precipitation or printing technique is suitably
be used for applying a fluorescent material on the glass
substrate regardless of black and white or color
display.

15 An ordinary metal back 95 is arranged on the
inner surface of the fluorescent film 94. The metal
back 95 is provided in order to enhance the luminance
of the display panel by causing the rays of light
emitted from the fluorescent bodies and directed to
20 the inside of the enclosure to turn back toward the
face plate 96, to use it as an electrode for applying
an accelerating voltage to electron beams and to
protect the fluorescent bodies against damages that
may be caused when negative ions generated inside the
25 enclosure collide with them. It is prepared by smoothing
the inner surface of the fluorescent film 94 (in an
operation normally called "filming") and forming an Al

1 film thereon by vacuum deposition after forming the
fluorescent film 94.

A transparent electrode (not shown) may be
formed on the face plate 96 facing the outer surface
5 of the fluorescent film 94 in order to raise the
conductivity of the fluorescent film 94.

Care should be taken to accurately align each
set of color fluorescent bodies and an electron-
emitting device, if a color display is involved, before
10 the above listed components of the enclosure are
bonded together.

The enclosure 98 is then evacuated by way of an
exhaust pipe (not shown) to a degree of vacuum of
approximately 10^{-6} and hermetically sealed.

15 After evacuating the enclosure to a desired
degree of vacuum by way of an exhaust pipe (not shown),
a voltage is applied to the device electrodes of each
device by way of external terminals Dxl through Dxm and
Dyl through Dyn for a forming operation and then
20 desired organic substances are fed in under a vacuum
condition for an activation process in order to
produce an electron-emitting region 3 of the device.

Most preferably, a baking operation is carried
out at 80°C to 200°C for 3 to 15 hours, during which the
25 vacuum system in the enclosure is switched to an
ultra-high vacuum system comprising an ion pump or the
like. The switch to an ultra-high vacuum system and

1 the baking operation are intended to ensure the
surface conduction electron-emitting device a
satisfactorily monotonically increasing characteristic
(MI characteristic) for both the device current I_f and
5 the emission current I_e and, therefore, this objective
may be achieved by some other means under different
conditions. A getter operation may be carried out
after sealing the enclosure 98 in order to maintain
that degree of vacuum in it. A getter operation is an
10 operation of heating a getter (not shown) arranged at
a given location in the enclosure 98 immediately before
of after sealing the enclosure 98 by resistance heating
or high frequency heating to produce a vapor deposition
film. A getter normally contains Ba as a principle
15 ingredient and the formed vapor deposition film can
typically maintain the inside of the enclosure to a
degree of 1×10^{-5} to 10^{-7} Torr by its adsorption
effect.

An image-forming apparatus according to the
20 invention and having a configuration as described above
is operated by applying a voltage to each electron-
emitting device by way of the external terminal Doxl
through Doxm and Doyle through Doyn to cause the
electron-emitting devices to emit electrons. Meanwhile,
25 a high voltage is applied to the metal back 85 or the
transparent electrode (not shown) by way of high voltage
terminal Hv to accelerate electron beams and cause them

1 to collide with the fluorescent film 94, which by turn
is energized to emit light to display intended images.

While the configuration of a display panel to be
suitably used for an image-forming apparatus according
5 to the invention is outlined above in terms of
indispensable components thereof, the materials of
the components are not limited to those described above
and other materials may appropriately be used depending
on the application of the apparatus. Input signals
10 for the above image-forming apparatus (is not limited
to NTSC signals and signals in other ordinary television
systems such as PAL and SECAM and those of television
systems with a greater number of scanning lines (such
as MUSE and other high definition systems) may be made
15 compatible with the apparatus.

The basic ideal of the present invention may be
utilized to provide not only display apparatuses for
television but also those for television conferencing,
computer systems and other applications. Additionally,
20 an image-forming apparatus to be used for an optical
printer comprising a photosensitive drum may be
realized on the basis of the present invention.

Examples

Now, the present invention will be described in
25 greater detail by way of examples.

Example 1

Device specimens used in this example had a basic

1 configuration same as the one illustrated in the plan
view of Fig. 1A and the sectional view of Fig. 1B. Four
identical devices were formed on a substrate 1. Note
that the reference numeral in Fig. 11 denote respective
5 components identical with those of Figs. 1A and 1B.

The method of manufacturing the devices was
basically same as the one illustrated in Figs. 2A
through 2C. The basic configuration of the device
specimen and the method for manufacturing the same will
10 be described below by referring to Figs. 1A and 1B and
Figs. 2A through 2C.

Referring to Figs. 1A and 1B, the prepared
specimens of electron-emitting device comprised a
substrate 1, a pair of device electrodes 5 and 6, a
15 thin film 4 including an electron-emitting region 3.

The method used for manufacturing the devices
will be described below in terms of an experiment
conducted for the specimens, referring to Figs. 1A and
1B and Figs. 2A through 2C.

20 Step A:

After thoroughly cleansing a soda lime glass
plate a silicon oxide film was formed thereon to a
thickness of 0.5 microns by sputtering to produce a
substrate 1, on which a pattern of photoresist
25 (RD-2000N-41: available from Hitachi Chemical Co.,
Ltd.) was formed for a pair of device electrodes 5 and
6 and a gap G separating the electrodes and then Ti and

1 Ni were sequentially deposited thereon respectively to
thicknesses of 50 A and 1,000 A by vacuum deposition.
The photoresist pattern was dissolved by an organic
solvent and the Ni/Ti deposit film was treated by using
5 a lift-off technique to produce a pair of device
electrodes 5 and 6 having a width W1 of 300 microns
and separated from each other by a distance L1 of 3
microns.

Step B:

10 A Cr film was formed to a film thickness of
1,000 A by vacuum deposition, which was then subjected
to a patterning operation. Thereafter, organic Pd
(ccp4230: available from Okuno Pharmaceutical Co., Ltd.)
was applied to the Cr film by means of a spinner, while
15 rotating the film, and baked at 300°C for 10 minutes to
produce a thin film 2 for forming an electron-emitting
region, which was made of fine particles containing Pd
as a principal ingredient and had a film thickness of
100 angstroms and an electric resistance per unit area
20 of $2 \times 10^4 \Omega/\square$. Note that the term "a fine particle
film" as used herein refers to a thin film constituted
of a large number of fine particles that may be loosely
dispersed, tightly arranged or mutually and randomly
overlapping (to form an island structure under certain
25 conditions). The diameter of fine particles to be used
for the purpose of the present invention is that of
recognizable fine particles arranged in any of the above

1 described states.

Step C:

The Cr film and the baked thin film 2 for forming an electron-emitting region were etched by using an acidic etchant to produce a desired pattern.

Now, a pair of device electrodes 5 and 6 and a thin film 2 for forming an electron-emitting region were produced on the substrate 1.

Step D:

10 Then, a gauging system as illustrated in Fig. 3 was set in position and the inside was evacuated by means of an exhaust pump to a degree of vacuum of 2×10^{-5} torr. Subsequently, a voltage was applied to the device electrodes 5, 6 for electrically energizing the device (electric forming process) by the power source 31 provided there for applying a device voltage V_f to the device. Fig. 4B shows the waveform of the voltage used for the electric forming process.

In Fig. 4B, T_1 and T_2 respectively denote the pulse width and the pulse interval of the applied pulse voltage, which were respectively 1 millisecond and 10 milliseconds for the experiment. The wave height (the peak voltage for the forming operation) of the applied pulse voltage was increased stepwise with a step of 0.1 V.

25 During the forming operation, a resistance measuring pulse voltage of 0.1 V was inserted during each T_2 to determine the current resistance of the device. The

1 forming operation was terminated when the gauge for
the resistance measuring pulse voltages showed a
reading of resistance of approximately 1 M ohms. In
the experiment, the reading of the gauge for the
5 forming voltage V_{form} was 5.1 V, 5.0 V, 5.0 V and
5.15 V.

Step E:

Two pairs of devices that had undergone a
forming process were subjected to an activation process,
10 where voltages having a rectangular waveform (Fig. 4C)
with wave heights of 4 V and 14 V were respectively
applied to each pair of devices. Hereinafter, the
specimens subjected to a low resistance activation
process with 4 V will be referred to as devices A,
15 whereas the specimens subjected to a high resistance
activation process with 14 V will be referred to as
devices B. In the activation process, the above
described pulse voltages were applied to the device
electrodes of the respective devices in the gauging
20 system of Fig. 3, while observing the device current I_f
and the emission current I_e . The degree of vacuum in
the gauging system of Fig. 3 was 1.5×10^{-5} torr. The
activation process continued for 30 minutes for each
device.

25 An electron-emitting region 3 was then formed on
each of the devices to produce a complete electron-
emitting device.

1 In an attempt to see the properties and the
profile of the surface conduction electron-emitting
devices prepared through the preceding steps, a device
A and a device B were observed for electron-emitting
5 performance, using a gauging system as illustrated in
Fig. 3. The remaining pair of devices were observed
through a microscope.

 In the above observation, the distance between
the anode and the electron-emitting device was 4 mm and
10 the potential of the anode was 1 kV, while the degree
of vacuum in the vacuum chamber of the system was held
to 1×10^{-6} torr throughout the gauging operation.
A device voltage of 14 V was applied between the device
electrodes 5, 6 of each of the devices A and B to see
15 the device current I_f and the emission current I_e under
that condition. A device current I_f of approximately
10 mA began to flow through the device A immediately
after the start of measurement but the current
gradually declined and the emission current I_e also
20 showed a decline. On the other hand, a steady flow was
observed for both the device current I_f and the emission
current I_e in the device B from the start of measurement.
A device current I_f of 2.0 mA and an emission current I_e
of 1.0 μ A were observed for a device voltage of 14 V to
25 provides an electron emission efficiency $\theta = I_e/I_f(\%)$
of 0.05%. Thus, it will be seen that the device A showed
a large and unstable device current I_f in the initial

1 stages of measurement whereas the device B proved to be
stable and have an excellent electron emission
efficiency θ from the very start of measurement.

When the degree of vacuum in the activation
5 process was held to be 1.5×10^{-5} torr for a device B
and the device current I_f and the emission current I_e
were observed, sweeping the device with a triangular
pulse voltage with a frequency of approximately 0.005 Hz,
the device current I_f was such as indicated by the
10 broken line in Fig. 7. As seen from Fig. 7, the device
current I_f monotonically increased to approximately 5 V
and then showed a voltage-controlled-negative-resistance
above the 5 V level. The device voltage at which the
device current I_f reaches a peak is referred to V_P ,
15 which was 5 V for the specimen. It should be noted
that the device current I_f was reduced to a fraction of
the maximum device current or approximately 1 mA beyond
10 V.

When observed through a microscope, the devices
20 A and B showed profiles similar to those illustrated in
Figs. 6B and 6A respectively. From a comparison between
Fig. 6B and Fig. 6A, it was found that the device A
carried a coat formed in the area of the thin film
between the device electrodes that had been transformed,
25 while in case of the device B, a coat was formed mainly
on the high potential side from part of the transformed
area along the direction along which a voltage was

1 applied to the device in the activation process.
When observed through an FESEM having large magnifying
power, it was found that the coat existed around part
of the fine metal particles and in part of the inter-
5 particle space of the device.

When observed through a TEM or a Raman
microscope, it was found that the coat was made of
graphite and amorphous carbon.

From these observations, it may be safe to say
10 that carbon was produced in the area of the thin film of
the device A that had been transformed by the forming
process as the area was activated by a voltage below
the voltage level of V_p required for voltage-controlled-
negative-resistance as described above so that the
15 carbon coat formed between the high and low potential
sides of the transformed area of the thin film provided
a current path for the device current through which a
large device current was allowed to flow at a rate
several times greater than the device current of the
20 device B from the very beginning.

Contrary to this, the device B was activated by
a voltage above the voltage level of V_p required for
voltage-controlled-negative-resistance in a high
resistance activation process so that, if a carbon coat
25 had been formed, it may have been electrically disrupted
to ensure a stable device current to flow from the
beginning.

1 Thus, an electron-emitting device having a
device current I_f and a emission current I_e that are
stable and capable of efficiently emitting electron
can be prepared by a high resistance activation process.

5 Example 2

In this example, a large number of surface
conduction electron-emitting devices were arranged to a
simple matrix arrangement to produce an image-forming
apparatus.

10 Fig. 13 is an enlarged schematic partial plan
view of the substrate of the electron source of the
apparatus. Fig. 14 is an enlarged schematic sectional
side view of the substrate of Fig. 13 taken along line
A-A'. Note that reference symbols in Figs. 13, 14,
15 15A through 15D and 16E through 16H respectively denote
identical items throughout the drawings. Thus,
reference numerals 81, 82 and 83 respectively denote a
substrate, an X-directional wiring corresponding to an
external terminal D_{xm} (also referred to as a lower
20 wiring) and a Y-direction wiring corresponding to an
external terminal D_{yn} (also referred to as an upper
wiring), whereas reference numeral 4 denotes a thin film
including an electron-emitting region, reference
numerals 5 and 6 denote a pair of device electrodes and
25 reference numerals 141 and 142 respectively denotes an
interlayer insulation layer and a contact hole for
connecting a device electrode 5 and a lower wiring 82.

1 Now, the method of manufacturing the device
specimens will be described below in terms of an
experiment conducted for the apparatus, referring to
Figs. 15A through 15D and 16E through 16H.

5 Step A:

 After thoroughly cleansing a soda lime glass
plate a silicon oxide film was formed thereon to a
thickness of 0.5 microns by sputtering to produce a
substrate 81, on which a photoresist (AZ1370: available
10 from Hoechst Corporation) was formed by means of a
spinner, while rotating the film, and baked. Thereafter,
a photo-mask image was exposed to light and developed
to produce a resist pattern for the lower wirings 82
and then the deposited Au/Cu film was wet-etched to
15 produce lower wires 82 having a desired profile
(Fig. 15A).

Step B:

 A silicon oxide film was formed as an interlayer
insulation layer 141 to a thickness of 1.0 micron by RF
20 sputtering (Fig. 15B).

Step C:

 A photoresist pattern was prepared for producing
a contact hole 142 in the silicon oxide film deposited
in Step B, which contact hole 142 was then actually
25 formed by etching the interlayer insulation layer,
using the photoresist pattern for a mask. RIE (Reactive
Ion Etching) using CF_4 and H_2 gas was employed for the

1 etching operation (Fig. 15C).

Step D:

Thereafter, a pattern of photoresist (RD-2000N: available from Hitach Chemical Co., Ltd.) was formed
5 for a pair of device electrodes 5 and 6 and a gap G separating the electrodes and then Ti and Ni were sequentially deposited thereon respectively to thicknesses of 50 Å and 1,000 Å by vacuum deposition. The photoresist pattern was dissolved by an organic
10 solvent and the Ni/Ti deposit film was treated by using a lift-off technique to produce a pair of device electrodes 5 and 6 having a width W1 of 300 microns and separated from each other by a distance G of 3 microns (Fig. 15D).

15 Step E:

After forming a photoresist pattern on the device electrodes 5, 6 for upper wirings 83, Ti and Au were sequentially deposited by vacuum deposition to respective thicknesses of 5 nm and 500 nm and then
20 unnecessary areas were removed by means of the lift-off technique to produce upper wirings 83 having a desired profile (Fig. 16E).

Step F:

A mask of the thin film 2 was prepared for
25 forming the electron-emitting region of the device. The mask had an opening for the gap L1 separating the device electrodes and its vicinity. The mask was used

1 to form a Cr film 151 to a film thickness of 1,000 Å
by vacuum deposition, which was then subjected to a
patterning operation. Thereafter, organic Pd (ccp4230:
available from Okuno Pharmaceutical Co., Ltd.) was
5 applied to the Cr film by means of a spinner, while
rotating the film, and baked at 300°C for 10 minutes
to produce a thin film 2 for forming an electron-
emitting region, which was made of fine particles
containing Pd as a principal ingredient and had a
10 film thickness of 8.5 nm and an electric resistance per
unit area of $3.9 \times 10^4 \Omega/\square$. Note that the term "a
fine particle film" as used herein refers to a thin
film constituted of a large number of fine particles
that may be loosely dispersed, tightly arranged or
15 mutually and randomly overlapping (to form an island
structure under certain conditions). The diameter of
fine particles to be used for the purpose of the present
invention is that of recognizable fine particles
arranged in any of the above described states (Fig. 16F).

20 Step G:

The Cr film 151 and the baked thin film 2 for
forming an electron-emitting region were etched by using
an acidic etchant to produce a desired pattern (Fig. 16G).

Step H:

25 Then, a pattern for applying photoresist to the
entire surface area except the contact hole 142 was
prepared and Ti and Au were sequentially deposited by

1 vacuum deposition to respective thicknesses of 5 nm and
500 nm. Any unnecessary areas were removed by means of
the lift-off technique to consequently bury the
contact hole 142.

5 Now, a lower wirings 82, an interlayer
insulation layer 141, upper wirings 83, a pair of
device electrodes 5 and 6 and a thin film 2 for forming
an electron-emitting region were produced on the
substrate 81 (Fig. 16H).

10 In an experiment, an image-forming apparatus
was produced by using an electron source prepared in
the above experiment. This apparatus will be described
by referring to Figs. 8 and 9.

A substrate 81 carrying thereon a large number
15 of surface conduction electron-emitting devices
prepared according to the above described process was
rigidly fitted to a rear plate 91 and thereafter a face
plate (prepared by forming a fluorescent film 94 and a
metal back 95 on a glass substrate 93) was arranged 5 mm
20 above the substrate 81 by interposing a support frame
92 therebetween. Frit glass was applied to junction
areas of the face plate 96, the support frame 92 and
the rear plate 91, which were then baked at 400°C for
10 minutes in the atmosphere and bonded together. The
25 substrate 81 was also firmly bonded to the rear plate
91 by means of frit glass (Fig. 9).

In Fig. 9, reference numeral denotes

1 electron-emitting devices and numerals 82 and 83
respectively denotes X-directional wirings and
Y-directional wirings.

5 While the fluorescent film 94 may be solely
made of fluorescent bodies if the image-forming
apparatus is for black and white pictures, firstly
black stripes were arranged and then the gaps separating
the black stripes were filled with respective fluorescent
bodies for primary colors to produce a fluorescent film
10 94 in this experiment. The black stripes were made of a
popular material containing graphite as a principal
ingredient. The fluorescent bodies were applied to the
glass substrate 93 by using a slurry method.

15 A metal back 95 is normally arranged on the
inner surface of the fluorescent film 94. In this
experiment, a metal back was prepared by producing an
Al film by vacuum deposition on the inner surface of
the fluorescent film 94 that had been smoothed in a
so-called filming process.

20 The face plate 96 may be additionally provided
with transparent electrodes (not shown) arranged close
to the outer surface of the fluorescent film 94 in
order to improve the conductivity of the fluorescent
film 94, no such electrodes were used in the experiment
25 because the metal back proved to be sufficiently
conductive.

The fluorescent bodies were carefully aligned

1 with the respective electron-emitting devices before
the above described bonding operation.

The prepared glass container was then evacuated
by means of an exhaust pipe (not shown) and an exhaust
5 pump to achieve a sufficient degree of vacuum inside
the container. Thereafter, the thin films 2 of the
electron-emitting devices 84 were subjected to an
electric forming operation, where a voltage was applied
to the device electrodes 5, 6 of the electron-emitting
10 devices 84 by way of the external terminals Doxl through
Doxm and Doyl through Doyn to produce an electron-
emitting region 3 in each device. The voltage used in
the forming operation had a waveform same as the one
shown in Fig. 4B.

15 Referring to Fig. 4B, T1 and T2 were respectively
1 millisecons and 10 millisecons and the electric
forming operation was carried out in vacuum of a degree
of approximately 1×10^{-5} torr.

Dispersed fine particles containing palladium as
20 a principal ingredient were observed in the electron-
emitting region 3 of each device that had been produced
in the above process. The fine particles had an average
particle size of 30 angstroms.

Thereafter, the devices were subjected to a
25 high resistance activation process, where a voltage
having a rectangular waveform same as that of the
voltage used in the forming operation and a wave height

1 of 14 V was applied to each device, observing the
device current I_f and the emission current I_e .

Finished electron-emitting devices 84 having
an electron-emitting region 3 were produced after the
5 forming and activation processes.

Subsequently, the enclosure was evacuated by
means of an oil-free ultra-high vacuum device to a
degree of vacuum of approximately 10^{-6} torr and then
hermetically sealed by melting and closing the exhaust
10 pipe (not shown) by means of a gas burner.

Finally, the apparatus was subjected to a getter
process using a high frequency heating technique in order
to maintain the degree of vacuum in the apparatus after
the sealing operation.

15 The electron-emitting devices of the above
image-forming apparatus were then caused to emit
electrons by applying a scan signal and a modulation
signal from a signal generating means (not shown)
through the external terminals Dx1 through DxM and Dy1
20 through DyN and the emitted electrons were accelerated
by applying a high voltage of 5 kV to the metal back 95
or the transparent electrodes (not shown) via the high
voltage terminal Hv so that they collides with the
fluorescent film 94 until the latter was energized to
25 emit light and produce an image. Both the device current
 I_f and the emission current I_e of each device were
similar to those illustrated in Fig. 7 by solid lines

1 to prove the device operated stably from the initial
stages. The emission current I_e was such that it
could sufficiently meet the requirement of brightness
of 100 fL to 150 fL of a television set.

5 Example 3

Specimens of electron-emitting device were
prepared as in the case of Example 1.

Each of the prepared electron-emitting devices
had a device width W_2 of 300 μm and the thin film 2 for
10 an electron-emitting region of the device had a film
thickness of 10 nm and an electric resistance per unit
area of $5 \times 10^4 \Omega/\square$. Otherwise, the devices were same
as their counterparts of Example 1.

Then, a gauging system as illustrated in Fig. 3
15 was set in position and the inside was evacuated by
means of a magnetic levitation pump to a degree of
vacuum of 2×10^{-8} torr. Subsequently, a voltage was
applied to the device electrodes 5, 6 for electrically
energizing the device (electric forming process) by the
20 power source 31 provided there for applying a device
voltage V_f to the device. Fig. 4B shows the waveform
of the voltage used for the electric forming process.

In Fig. 4B, T_1 and T_2 respectively denote the
pulse width and the pulse interval of the applied pulse
25 voltage, which were respectively 1 millisecond and 10
milliseconds for the experiment. The wave height (the
peak voltage for the forming operation) of the applied

1 pulse voltage was increased stepwise with a step of
0.1 V. During the forming operation, a resistance
measuring pulse voltage of 0.1 V was inserted during
each T2 to determine the current resistance of the
5 device. The forming operation and the application of
the voltage to the device were terminated when the
gauge for the resistance measuring pulse voltages showed
a reading of resistance of approximately 1 M ohms. In
the experiment, the reading of the gauge for the
10 forming voltage V_{form} was 5.1 V.

A prepared sample device was then subjected to
an activation process in an atmosphere containing
acetone (having a vapor pressure of 233 hPa at 20°C)
to a pressure of approximately 1×10^{-5} torr for 20
15 minutes. Fig. 4C shows the waveform of the voltage
applied to the device in the activation process.

In Fig. 4C, T3 and T4 respectively denote the
pulse width and the pulse interval of the voltage wave,
which were 10 microseconds and 10 milliseconds in the
20 experiment. The wave height of the rectangular wave
was 14 V.

Thereafter, the vacuum chamber of the gauging
system was evacuated further to approximately 1×10^{-8}
torr.

25 During the experiment, organic substances to be
used for the activation process were introduced via a
feeding system (Fig. 12) comprising a needle valve and

1 the inside pressure of the vacuum chamber was maintained
to a substantially constant level.

Then, the performance of the device was
determined by applying a voltage of 1 kV to the anode
5 in the gauging system, where the device was separated
from the anode by a distance H of 4 mm and the inside
of the vacuum chamber was maintained to 1×10^{-8} torr.

It was observed that, when the device voltage
was 14 V, the device current and the emission current
10 were respectively 2 mA and 1 μ A to prove an electron
emission efficiency θ of 0.05%. Table 1 shows the
pulse width dependency of the device when the voltage
was 14 V, the pulse interval was 16.6 msec. and the
pulse width was 30 μ sec., 100 μ sec. and 300 μ sec.

15 Example 4

Device specimens were prepared under conditions
same as those of Example 3 except that n-dodecan (having
a vapor pressure of 0.1 hPa at 20°C) was used in place
of acetone for the activation process.

20 When one of the prepared devices was tested to
see its I_f and I_e as in the case of Example 3 above, the
device current and the emission current were respectively
2.2 mA and 1 μ A for a device voltage of 14 V to prove an
electron emission efficiency θ of 0.045%. Table 1 shows
25 the pulse width dependency of the device when tested
under the conditions same as those of Example 3.

1 Example 5

Device specimens were prepared under conditions same as those of Example 3 except that the activation process was carried out for two hours by using formaldehyde (having a vapor pressure of 4,370 hPa at 20°C) in place of acetone.

When one of the prepared devices was tested to see its I_f and I_e as in the case of Example 3 above, the device current and the emission current were respectively 1 mA and 0.2 μ A for a device voltage of 14 V to prove an electron emission efficiency θ of 0.02%.

Example 6

Device specimens were prepared under conditions same as those of Example 3 except that n-hexane (having a vapor pressure of 160 hPa at 20°C) was used in place of acetone for the activation process.

When one of the prepared devices was tested to see its I_f and I_e as in the case of Example 3 above, the device current and the emission current were respectively 1.8 mA and 0.8 μ A for a device voltage of 14 V to prove an electron emission efficiency θ of 0.044%. Table 1 shows the pulse width dependency of the device when tested under the conditions same as those of Example 3.

25 Example 7-a

Device specimens were prepared under conditions same as those of Example 3 except that n-undecane

1 (having a vapor pressure of 0.35 hPa at 20°C) was used
in place of acetone for the activation process.

When one of the prepared devices was tested to
see its I_f and I_e as in the case of Example 3 above,
5 the device current and the emission current were
respectively 1.5 mA and 0.6 μ A for a device voltage of
14 V to prove an electron emission efficiency θ of
0.04%. Table 1 shows the pulse width dependency of the
device when tested under the conditions same as those
10 of Example 3.

Example 7-b

Device specimens were prepared under conditions
same as those of Example 1 except organic substances
were not introduced into the gauging system and the
15 activation process was carried out in a vacuum/exhaust
system having an oily atmosphere (connected directly to
a rotary pump and a turbo pump and capable of producing
a degree of vacuum of 5×10^{-7} torr).

When one of the prepared devices was tested to
20 see its I_f and I_e as in the case of Example 1 above,
the device current and the emission current were
respectively 2.2 mA and 1.1 μ A for a device voltage of
14 V to prove an electron emission efficiency θ of
0.045%. Table 1 shows the pulse width dependency of
25 the device when tested under the conditions same as
those of Example 3.

1 Example 8

 In this example, an image-forming apparatus
comprising a large number of surface conduction
electron-emitting devices arranged to a simple matrix
5 arrangement was prepared as in the case of Example 2.

 Firstly, a glass container containing an
electron source like that of Example 2 was produced
and the glass container was evacuated to a degree of
vacuum of 1×10^{-6} torr via an exhaust pipe (not shown)
10 by means of an oil-free vacuum pump.

 Thereafter, the thin films 2 of the electron-
emitting devices 84 were subjected to an electric
forming operation, where a voltage was applied to the
device electrodes 5, 6 of the electron-emitting
15 devices 84 by way of the external terminals Doxl through
Doxm and Doyl through Doyn to produce an electron-
emitting region 3 in each device. The voltage used
in the forming operation had a waveform same as the
one shown in Fig. 4B.

20 Dispersed fine particles containing palladium
as a principal ingredient were observed in the electron-
emitting region 3 of each device that had been produced
in the above process. The fine particles had an
average particle size of 30 angstroms.

25 Thereafter, the devices were subjected to an
activation process, where acetone was introduced into
the glass container to a pressure of 1×10^{-3} torr and

1 a voltage was applied to the device electrodes 5, 6
of each electron-emitting device 84 via appropriate
ones of the external terminals Doxl through Doxm and
Doyl through Doyn. Fig. 4C shows the waveform of the
5 voltage used for the activation process.

Subsequently, the acetone contained in the
container was evacuated to produce finished electron-
emitting devices.

Then, the components of the apparatus was baked
10 at 120°C for 10 hours in vacuum of a degree of
approximately 1×10^{-6} torr and the enclosure was
hermetically sealed by melting and closing the exhaust
pipe (not shown) by means of a gas burner.

Finally, the apparatus was subjected to a
15 getter process using a high frequency heating technique
in order to maintain the degree of vacuum in the
apparatus after the sealing operation. A getter
containing Ba as a principal component had been
arranged in a predetermined position (not shown) before
20 hermetically sealing the enclosure to form a film
inside the enclosure through vapor deposition.

The electron-emitting devices of the above
image-forming apparatus were then caused to emit
electrons by applying a scan signal and a modulation
25 signal from a signal generating means (not shown)
through the external terminals Dxl through Dxm and Dyl
through Dyn and the emitted electrons were accelerated

1 by applying a high voltage of 7 kV to the metal back
95 or the transparent electrodes (not shown) via the
high voltage terminal Hv so that they collide with the
fluorescent film 94 until the latter was energized to
5 emit light and produce an image.

Example 9

This example deals with an image-forming
apparatus comprising a large number of surface
conduction electron-emitting devices and control
10 electrodes (grids).

Since an apparatus to be dealt in this example
can be prepared in a way as described above concerning
the image-forming apparatus of Example 2, the method
of manufacturing the same will not be described any
15 further.

The configuration of the apparatus will be
described in terms of the electron source of the
apparatus prepared by arranging a number of surface
conduction electron-emitting devices.

20 Figs. 17 and 18 are schematic plan views of
two different substrates of electron source alternatively
used in the image-forming apparatus of Example 9.

Firstly referring to Fig. 17, S denotes an
insulator substrate typically made of glass and ES
25 denotes an surface conduction electron-emitting device
arranged on the substrate S and shown in a dotted
circle, whereas E1 through E10 denote wiring electrodes

1 for wiring the surface conduction electron-emitting
devices, which are arranged in columns on the
substrate along the X-direction (hereinafter referred
to as device columns). The surface conduction electron-
5 emitting devices of each device column are electrically
connected in parallel with each other by a pair of
wiring electrodes. (For instance, the devices of the
first device column are connected in parallel with each
other by the wiring electrodes E1 and E10.)

10 In the apparatus of this example comprising the
above described electron source, the electron source can
drive any device column independently by applying an
appropriate drive voltage to the related wiring
electrodes. More specifically, a voltage exceeding
15 the electron emission threshold level is applied to
the device columns to be driven to emit electrons,
whereas a voltage below the electron emission threshold
level (e.g., 0 V) is applied to the remaining device
columns. (A drive voltage exceeding the electron
20 emission threshold level is referred to as $VE[V]$
hereinafter.)

In Fig. 18 illustrating another electron source
that can be used for this example, S denotes an
insulator substrate typically made of glass and ES
25 denotes an surface conduction electron-emitting
device arranged on the substrate S and shown in a
dotted circle, whereas E'1 through E'6 denote wiring

1 electrodes for wiring the surface conduction electron-
emitting devices, which are arranged in columns on
the substrate along the X-direction. The surface
conduction electron-emitting devices of each device
5 column are electrically connected in parallel with
each other by a pair of wiring electrodes.
Additionally, in this alternative electron source,
a single wiring electrode is arranged between any two
adjacent device columns to serve for the both columns.
10 For instance, a common wiring electrode E'2 serves for
both the first device column and the second device
column. This arrangement of wiring electrodes is
advantageous in that, if compared with the arrangement
of Fig. 17, the space separating any two adjacent columns
15 of surface conduction electron-emitting devices can be
significantly reduced.

In the apparatus of this example comprising the
above described electron source, the electron source can
drive any device column independently by applying an
20 appropriate drive voltage to the related wiring
electrodes. More specifically, $VE[V]$ is applied to
the device columns to be driven to emit electrons,
whereas 0 V is applied to the remaining device columns.
For instance, only the devices of the third column can
25 be driven to operate by applying 0 V to the wiring
electrodes E'1 through E'3 and $VE[V]$ to the wiring
electrodes E'4 through E'6. Consequently, $VE-0=VE[V]$

1 is applied to the devices of the third column, whereas
0[V], $0-0=0[V]$ or $VE-VE=0[V]$, is applied to all the
devices of the remaining columns. Likewise, the
devices of the second and the fifth columns can be
5 driven to operate simultaneously by applying 0[V] to
the wiring electrodes E'1, E'2 and E'6 and VE[V] to
the wiring electrodes E'3, E'4 and E'5. In this way,
the devices of any device column of this electron
source can be driven selectively.

10 While each device column has twelve (12) surface
conduction electron-emitting devices arranged along the
X-direction in the electron sources of Figs. 17 and
18, the number of devices to be arranged in a device
column is not limited thereto and a greater number of
15 devices may alternatively be arranged. Additionally,
while there are five (5) device columns in each of the
electron sources, the number of device columns is not
limited thereto and a greater number of device columns
may alternatively be arranged.

20 Now, a panel type CRT incorporating an electron
source of the above described type will be described.

Fig. 19 is a schematic perspective view of a
panel type CRT incorporating an electron source as
illustrated in Fig. 17. In Fig. 19, VC denotes a glass
25 vacuum container provided with a face plate FP for
displaying images. A transparent electrode is arranged
on the inner surface of the face plate PH and red, green

1 and blue fluorescent members are applied onto the
transparent electrode in the form of a mosaic or
stripes without interfering with each other. To
simplify the illustration, the transparent electrodes
5 and the fluorescent members are collectively indicated
by PH in Fig. 19. A black matrix or black stripes
known in the field of CRT may be arranged to fill the
blank areas of the transparent electrode that are not
occupied by the fluorescent matrix or stripes.
10 Similarly, a metal back layer of any known type may be
arranged on the fluorescent members. The transparent
electrode is electrically connected to the outside of
the vacuum container by way of a terminal EV so that an
voltage may be applied thereto in order to accelerate
15 electron beams.

In Fig. 19, S denotes the substrate of the
electron source rigidly fitted to the bottom of the
vacuum container VC, on which a number of surface
conduction electron-emitting devices are arranged as
20 described above by referring to Fig. 17. More
specifically, a total of 200 device columns, each
having 200 devices, are arranged on the substrate.
Each device column is provided with a pair of wiring
electrodes and the wiring electrodes of the apparatus
25 are connected to the electrodes terminals Dp1 through
Dp200 and Dm1 through Dm200 arranged on the respective
opposite sides of the panel in an alternate manner so

1 that electric drive signals may be applied to the
 devices from outside of the vacuum container.

 In an experiment using a finished glass
 container VC (Fig. 19), the container was evacuated to
5 a sufficient degree of vacuum via an exhaust pipe
 (not shown) by means of an vacuum pump and, thereafter,
 the electron-emitting devices ES were subjected to an
 electric forming operation, where a voltage was applied
 to the devices by way of the external terminals DPl
10 through DP200 and Dm1 through Dm200. The voltage used
 in the forming operation had a waveform same as the one
 shown in Fig. 4B. In the experiment, T1 and T2 were
 respectively 1 milliseconds and 10 milliseconds and
 the electric forming operation was carried out in
15 vacuum of a degree of approximately 1×10^{-5} torr.

 Thereafter, the devices were subjected to an
 activation process, where acetone was introduced into
 the glass container to a pressure of 1×10^{-4} torr and
 a voltage was applied to the electron-emitting devices
20 ES via the external terminals Dpl through Dp200 and Dm1
 through Dm200. Then, the acetone contained in the
 container was evacuated to produce finished electron-
 emitting devices.

 Dispersed fine particles containing palladium as
25 a principal ingredient were observed in the electron-
 emitting region of each device that had been produced in
 the above process. The fine particles had an average

1 particle size of 30 angstroms. Subsequently, the
vacuum system used for the experiment was switched to
an ultra-high vacuum system comprising an oil-free ion
pump. Thereafter, the components of the apparatus was
5 baked at 120°C for a sufficient period of time in
vacuum of a degree of approximately 1×10^{-6} torr.

Then, the enclosure was hermetically sealed by
melting and closing the exhaust pipe (not shown) by
means of a gas burner.

10 Finally, the apparatus was subjected to a
getter process using a high frequency heating technique
in order to maintain the degree of vacuum in the
apparatus after the sealing operation and finish the
operation of preparing the image-forming apparatus.

15 Stripe-shaped grid electrodes GR are arranged
between the substrate S and the face plate. There are
provided a total of 200 grid electrodes GR arranged in
a direction perpendicular to that of the device columns
(or in the Y-direction) and each grid electrode has a
20 given number of openings Gh for allowing electron beams
to pass therethrough. More specifically, while a
circular opening Gh is typically provided for each
surface conduction electron-emitting device, the
openings may alternatively be realized in the form of a
25 mesh. The grid electrodes are electrically connected to
the outside of the vacuum container via respective
electric terminals G1 through G200. Note that the grid

1 electrodes may be differently arranged in terms of
shape and location from those of Fig. 19 so long as
they can successfully modulate electron beams emitted
from the surface conduction electron-emitting devices.
5 For instance, they may be arranged around or in the
vicinity of the surface conduction electron-emitting
devices.

The above described display panel comprises
surface conduction electron-emitting devices arranged
10 in 200 device columns and 200 grid electrodes to form
an X-Y matrix of 200 x 200. With such an arrangement,
an image can be displayed on the screen on a line by
line basis by applying a modulation signal to the grid
electrodes for a single line of an image in synchronism
15 with the operation of driving (scanning) the surface
conduction electron-emitting devices on a column by
column basis to control the irradiation of electron
beams onto the fluorescent film.

Fig. 20 is a block diagram of an electric
20 circuit to be used for driving the display panel of
Fig. 19. In Fig. 20, the circuit comprises the
display panel 1000 of Fig. 19, a decode circuit 1001
for decoding composite image signals transmitted from
outside, a serial/parallel conversion circuit 1002, a
25 line memory 1003, a modulation signal generation
circuit 1004, a timing control circuit 1005 and a scan
signal generating circuit 1006. The electric terminals

1 of the display panel 1000 are connected to the related
circuits. Specifically, the terminal EV is connected
to a voltage source HV for generating an acceleration
voltage of 10[kV] and the terminals G1 through G200 are
5 connected to the modulation signal generation circuit
1004 while the terminals Dp1 through Dp200 are connected
to the scan signal generation circuit 1006 and the
terminals Dm1 through Dm200 are grounded.

Now, how each component of the circuit operates
10 will be described. The decode circuit 1001 is a
circuit for decoding incoming composite image signals
such as NTSC television signals and separating
brightness signals and synchronizing signals from the
received composite signals. The former are sent to
15 the serial/parallel conversion circuit 1002 as data
signals and the latter are forwarded to the timing
control circuit 1005 as Tsync signals. In other words,
the decode circuit 1001 rearranges the values of
brightness of the primary colors of RGB corresponding
20 to the arrangement of color pixels of the display panel
1000 and serially transmits them to the serial/parallel
conversion circuit 1002. It also extracts vertical and
horizontal synchronizing signals and transmits them to the
timing control circuits 1005. The timing control
25 circuit 1005 generates various timing control signals
in order to coordinate the operational timings of
different components by referring to said synchronizing

1 signal Tsync. More specifically, it transmits Tsp
signals to the serial/parallel conversion circuit 1002,
Tmry signals to the line memory 1003, Tmod signals to
the modulation signal generation circuit 1004 and Tscan
5 signals to the scan signal generation circuit 1005.

The serial/parallel conversion circuit 1002
samples brightness signals Data it receives from the
decode circuit 1001 on the basis of timing signals Tsp
and transmits them as 200 parallel signals I1 through
10 I200 to the line memory 1003. When the serial/parallel
conversion circuit 1002 completes an operation of
serial/parallel conversion on a set of data for a
single line of an image, the timing control circuit
1005 a write timing control signal Tmry to the line
15 memory 1003. Upon receiving the signal Tmry, it stores
the contents of the signals I1 through I200 and transmits
them to the modulation signal generation circuit 1004
as signals I'1 through I'200 and holds them until it
receives the next timing control signal Tmry.

20 The modulation signal generation circuit 1004
generates modulation signals to be applied to the grid
electrodes of the display panel 1000 on the basis of
the data on the brightness of a single line of an image
it receives from the line memory 1003. The generated
25 modulation signals are simultaneously applied to the
modulation signal terminals G1 through G200 in
correspondence to a timing control signal Tmod generated

1 by the timing control circuit 1005. While modulation
signals typically operate in a voltage modulation mode
where the voltage to be applied to a device is
modulated according to the data on the brightness of
5 an image, they may alternatively operate in a pulse
width modulation mode where the length of the pulse
voltage to be applied to a device is modulated
according to the data on the brightness of an image.

The scan signal generation circuit 1006
10 generates voltage pulses for driving the device
columns of the surface conduction electron-emitting
devices of the display panel 1000. It operates to turn
on and off the switching circuits it comprises according
to timing control signals Tscan generated by the timing
15 control circuit 1005 to apply either a drive voltage
VE[V] generated by a constant voltage source DV and
exceeding the threshold level for the surface conduction
electron-emitting devices or the ground potential level
(0[V]) to each of the terminals Dp1 through Dp200.

20 As a result of coordinated operations of the
above described circuits, drive signals are applied to
the display panel 1000 with the timings as illustrated
in the graphs of Figs. 21A through 21F. Figs. 21A
through 21D show part of signals to be applied to the
25 terminals Dp1 through Dp200 of the display panel from
the scan signal generation circuit 1006. It is seen
that a voltage pulse having an amplitude of VE[V] is

1 applied sequentially to Dp1, Dp2, Dp3, ... within a
period of time for display a single line of an image.
On the other hand, since the terminals Dm1 through
Dm200 are constantly grounded and held to 0[V], the
5 device columns are sequentially driven by the voltage
pulse to emit electron beams from the first column.

In synchronism of this operation, the modulation
signal generation circuit 1004 applies modulation signals
to the terminals G1 through G200 for each line of an
10 image with the timing as shown by the dotted line in
Fig. 21F. Modulation signals are sequentially selected
in synchronism with the selection of scan signals until
an entire image is displayed. By continuously repeating
the above operation, moving images are displayed on the
15 display screen for television.

A flat panel type CRT comprising an electron
source of Fig. 17 has been described above. Now, a
panel type CRT comprising an electron source of Fig. 18
will be described below by referring to Fig. 22.

20 The panel type CRT of Fig. 22 is realized by
replacing the electron source of the CRT of Fig. 19
with the one illustrated in Fig. 18, which comprises
an X-Y matrix of 200 columns of electron-emitting
devices and 200 grid electrodes. Note that the 200
25 columns of surface conduction electron-emitting devices
are respectively connected to 201 wiring electrodes E1
through E201 and, therefore, the vacuum container is

1 provided with a total of 201 electrode terminals Ex1
through Ex201.

In an experiment using a finished glass container
VC (Fig. 22), the container was evacuated to a
5 sufficient degree of vacuum via an exhaust pipe (not
shown) by means of a vacuum pump and, thereafter, the
electron-emitting devices ES were subjected to an
electric forming operation, where a voltage was applied
to the devices by way of the external terminals Ex1
10 through Ex201. The voltage used in the forming
operation had a waveform same as the one shown in Fig.
4B. In the experiment, T1 and T2 were respectively 1
millisecond and 10 milliseconds and the electric
forming operation was carried out in vacuum of a degree
15 of approximately 1×10^{-5} torr.

Thereafter, the devices were subjected to an
activation process, where acetone was introduced into
the glass container to a pressure of 1×10^{-4} torr and
a voltage was applied to the electron-emitting devices
20 ES via the external terminals Dp1 through Dp200 and Dm1
through Dm200. Then, the acetone contained in the
container was evacuated to produce finished electron-
emitting devices.

Dispersed fine particles containing palladium as
25 a principal ingredient were observed in the electron-
emitting region of each device that had been produced in
the above process. The fine particles had an average

1 particle size of 30 angstroms. Subsequently, the
vacuum system used for the experiment was switched to
an ultra-high vacuum system comprising an oil-free ion
pump. Thereafter, the components of the apparatus was
5 baked at 120°C for a sufficient period of time in vacuum
of a degree of approximately 1×10^{-6} torr.

Then, the enclosure was hermetically sealed by
melting and closing the exhaust pipe (not shown) by
means of a gas burner.

10 Finally, the apparatus was subjected to a getter
process using a high frequency heating technique in
order to maintain the degree of vacuum in the apparatus
after the sealing operation and finish the operation of
preparing the image-forming apparatus.

15 Fig. 23 shows a block diagram of a drive circuit
for driving the display panel 1008. This circuit has a
configuration basically same as that of Fig. 20 except
the scan signal generation circuit 1007. The scan signal
generation circuit 1007 applies either a drive voltage
20 VE[V] generated by a constant voltage source DV and
exceeding the threshold level for the surface conduction
electron-emitting devices or the ground potential level
(0[V]) to each of the terminals of the display panel.

Figs. 24A through 24I show the timings with which
25 certain signals are applied to the display panel.
The display panel operates to display an image with the
timing as illustrated in Fig. 24A as drive signals shown

1 in Figs. 24B through 24E are applied to the electrode
terminals Ex1 through Ex4 from the scan signal
generation circuit 1007 and, consequently, voltages
as shown in Figs. 24F through 24H are sequentially
5 applied to the corresponding columns of surface
conduction electron-emitting devices to drive the
latter. In synchronism with this operation, modulation
signals are generated by the modulation signal generation
circuit 1004 with the timing as shown in Fig. 24I to
10 display images on the display screen.

An image-forming apparatus of the type realized
in this example operates very stably, showing full color
images with excellent gradation and contrast.

Example 10

15 Fig. 25 is a block diagram of the display
apparatus comprising an electron source realized by
arranging a number of surface conduction electron-
emitting devices and a display panel and designed to
display a variety of visual data as well as pictures of
20 television transmission in accordance with input signals
coming from different signal sources. Referring to Fig.
25, the apparatus comprises a display panel 25100, a
display panel drive circuit 25101, a display controller
25102, a multiplexer 25103, a decoder 25104, an
25 input/output interface circuit 25105, a CPU 25106, an
image generation circuit 25107, image memory interface
circuits 25108, 25109 and 25110, an image input interface

1 circuit 25111, TV signal receiving circuits 25112 and
25113 and an input section 25114. (If the display
apparatus is used for receiving television signals
that are constituted by video and audio signals,
5 circuits, speakers and other devices are required for
receiving, separating, reproducing, processing and
storing audio signals along with the circuits shown in
the drawing. However, such circuits and devices are
omitted here in view of the scope of the present
10 invention.)

Now, the components of the apparatus will be
described, following the flow of image data therethrough.

Firstly, the TV signal reception circuit 25113
is a circuit for receiving TV image signals transmitted
15 via a wireless transmission system using electromagnetic
waves and/or spatial optical telecommunication networks.
The TV signal system to be used is not limited to a
particular one and any system such as NTSC, PAL or
SECAM may feasibly be used with it. It is particularly
20 suited for TV signals involving a larger number of
scanning lines (typically of a high definition TV
system such as the MUSE system) because it can be used
for a large display panel comprising a large number of
pixels. The TV signals received by the TV signal
25 reception circuit 25113 are forwarded to the decoder
25104.

Secondly, the TV signal reception circuit 25112

1 is a circuit for receiving TV image signals transmitted
via a wired transmission system using coaxial cables
and/or optical fibers. Like the TV signal reception
circuit 25113, the TV signal system to be used is not
5 limited to a particular one and the TV signals received
by the circuit are forwarded to the decoder 25104.

The image input interface circuit 25111 is a
circuit for receiving image signals forwarded from an
image input device such as a TV camera or an image
10 pick-up scanner. It also forwards the received image
signals to the decoder 25104.

The image memory interface circuit 25110 is a
circuit for retrieving image signals stored in a video
tape recorder (hereinafter referred to as VTR) and the
15 retrieved image signals are also forwarded to the
decoder 25104.

The image memory interface circuit 25109 is a
circuit for retrieving image signals stored in a video
disc and the retrieved image signals are also forwarded
20 to the decoder 25104.

The image memory interface circuit 25108 is a
circuit for retrieving image signals stored in a device
for storing still image data such as so-called still
disc and the retrieved image signals are also forwarded
25 to the decoder 25104.

The input/output interface circuit 25105 is a
circuit for connecting the display apparatus and an

1 external output signal source such as a computer, a
computer network or a printer. It carries out input/
output operations for image data and data on characters
and graphics and, if appropriate, for control signals
5 and numerical data between the CPU 25106 of the display
apparatus and an external output signal source.

The image generation circuit 25107 is a
circuit for generating image data to be displayed on
the display screen on the basis of the image data and
10 the data on characters and graphics input from an
external output signal source via the input/output
interface circuit 25105 or those coming from the CPU
25106. The circuit comprises reloadable memories for
storing image data and data on characters and graphics,
15 read-only memories for storing image patterns
corresponding given character codes, a processor for
processing image data and other circuit components
necessary for the generation of screen images.

Image data generated by the circuit for display
20 are sent to the decoder 25104 and, if appropriate, they
may also be sent to an external circuit such as a
computer network or a printer via the input/output
interface circuit 25105.

The CPU 25106 controls the display apparatus
25 and carries out the operation of generating, selecting
and editing images to be displayed on the display screen.

For example, the CPU 25106 sends control signals

1 to the multiplexer 25103 and appropriately selects or
combines signals for images to be displayed on the
display screen. At the same time it generates control
signals for the display panel controller 25102 and
5 controls the operation of the display apparatus in
terms of image display frequency, scanning method
(e.g., interlaced scanning or non-interlaced scanning),
the number of scanning lines per frame and so on.

The CPU 25106 also sends out image data and
10 data on characters and graphic directly to the image
generation circuit 25107 and accesses external
computers and memories via the input/output interface
circuit 25105 to obtain external image data and data on
characters and graphics. The CPU 25106 may additionally
15 be so designed as to participate other operations of the
display apparatus including the operation of generating
and processing data like the CPU of a personal computer
or a word processor. The CPU 25106 may also be
connected to an external computer network via the
20 input/output interface circuit 25105 to carry out
computations and other operations, cooperating therewith.

The input section 25114 is used for forwarding
the instructions, programs and data given to it by the
operator to the CPU 25106. As a matter of fact, it may
25 be selected from a variety of input devices such as
keyboards, mice, joy sticks, bar code readers and
voice recognition devices as well as any combinations

1 thereof.

 The decoder 25104 is a circuit for converting
various image signals input via said circuits 25107
through 25113 back into signals for three primary
5 colors, luminance signals and I and Q signals.
Preferably, the decoder 25104 comprises image memories
as indicated by a dotted line in Fig. 25 for dealing
with television signals such as those of the MUSE
system that require image memories for signal conversion.
10 The provision of image memories additionally facilitates
the display of still images as well as such
operations as thinning out, interpolating, enlarging,
reducing, synthesizing and editing frames to be
optionally carried out by the decoder 25104 in
15 cooperation with the image generation circuit 25107 and
the CPU 25106.

 The multiplexer 25103 is used to appropriately
select images to be displayed on the display screen
according to control signals given by the CPU 25106.
20 In other words, the multiplexer 25103 selects certain
converted image signals coming from the decoder 25104
and sends them to the drive circuit 25101. It can also
divide the display screen in a plurality of frames to
display different images simultaneously by switching
25 from a set of image signals to a different set of image
signals within the time period for displaying a single
frame.

1 The display panel controller 25102 is a
circuit for controlling the operation of the drive
circuit 25101 according to control signals transmitted
from the CPU 25106.

5 Among others, it operates to transmit signals
to the drive circuit 25101 for controlling the sequence
of operations of the power source (not shown) for
driving the display panel in order to define the basic
operation of the display panel. It also transmits
10 signals to the drive circuit 25101 for controlling the
image display frequency and the scanning method (e.g.,
interlaced scanning or non-interlaced scanning) in
order to define the mode of driving the display panel.

 If appropriate, it also transmits signals to
15 the drive circuit 25101 for controlling the quality of
the images to be displayed on the display screen in
terms of luminance, contrast, color tone and sharpness.

 The drive circuit 25101 is a circuit for
generating drive signals to be applied to the display
20 panel 25100. It operates according to image signals
coming from said multiplexer 25103 and control signals
coming from the display panel controller 25102.

 A display apparatus according to the invention
and having a configuration as described above and
25 illustrated in Fig. 25 can display on the display panel
25100 various images given from a variety of image data
sources. More specifically, image signals such as

1 television image signals are converted back by the
decoder 25104 and then selected by the multiplexer
25103 before sent to the drive circuit 25101. On the
other hand, the display controller 25102 generates
5 control signals for controlling the operation of the
drive circuit 25101 according to the image signals for
the images to be displayed on the display panel 25100.
The drive circuit 25101 then applies drive signals to
the display panel 25100 according to the image signals
10 and the control signals. Thus, images are displayed on
the display panel 25100. All the above described
operations are controlled by the CPU 25106 in a
coordinated manner.

The above described display apparatus can not
15 only select and display particular images out of a number
of images given to it but also carry out various image
processing operations including those for enlarging,
reducing, rotating, emphasizing edges of, thinning out,
interpolating, changing colors of and modifying the
20 aspect ratio of images and editing operations including
those for synthesizing, erasing, connecting, replacing
and inserting images as the image memories incorporated
in the decoder 25104, the image generation circuit 25107
and the CPU 25106 participate such operations. Although
25 not described with respect to the above embodiment, it
is possible to provide it with additional circuits
exclusively dedicated to audio signal processing and

1 editing operations.

Thus, a display apparatus according to the invention and having a configuration as described above can have a wide variety of industrial and commercial applications because it can operate as a display apparatus for television broadcasting, as a terminal apparatus for video teleconferencing, as an editing apparatus for still and movie pictures, as a terminal apparatus for a computer system, as an OA apparatus such as a word processor, as a game machine and in many other ways.

It may be needless to say that Fig. 25 shows only an example of possible configuration of a display apparatus comprising a display panel provided with an electron source prepared by arranging a number of surface conduction electron-emitting devices and the present invention is not limited thereto. For example, some of the circuit components of Fig. 25 may be omitted or additional components may be arranged there depending on the application. For instance, if a display apparatus according to the invention is used for visual telephone, it may be appropriately made to comprise additional components such as a television camera, a microphone, lighting equipment and transmission/reception circuits including a modem.

Since a display apparatus according to the invention comprises a display panel that is provided

1 with an electron source prepared by arranging a large
number of surface conduction electron-emitting device
and hence adaptable to reduction in the depth, the
overall apparatus can be made very thin. Additionally,
5 since a display panel comprising an electron source
prepared by arranging a large number of surface
conduction electron-emitting devices is adapted to
have a large display screen with an enhanced luminance
and provide a wide angle for viewing, it can offer
10 really impressive scenes to the viewers with a sense
of presence.

[Advantages of the Invention]

As described above, the present invention
provides a method of manufacturing a surface conduction
15 electron-emitting device comprising a pair of
oppositely disposed device electrodes and a thin film
including an electron-emitting region arranged on a
substrate, wherein it comprises at least steps of
forming a pair of electrodes, forming a thin film
20 (including an electron-emitting region), conducting
an electric forming process and conducting an activation
process so that the electron emission performance of the
device that has hitherto been undeterminable can be
strictly controlled as the forming process and the
25 activation process are conducted in two separate steps
and a coat containing carbon in the form of graphite,
amorphous carbon or a mixture thereof as a principal

1 ingredient is formed on and around the electron-
emitting region under a controlled manner.

Preferably, the activation process comprises
steps of forming a coat containing carbon as a
5 principal ingredient on the thin film and applying a
voltage exceeding the voltage-controlled-negative-
resistance level to the pair of electrodes of the
device so that the coat containing carbon as a
principal ingredient may be formed on the high voltage
10 side from part of the electron-emitting region.
With such an arrangement, the produced electron-emitting
device can operate stably from the initial stages of
operation with a low device current and a high
efficiency.

15 According to the invention, there is also
provided an electron source designed to emit electrons
in accordance to input signals and comprising a
plurality of electron-emitting devices of the above
described type on a substrate, wherein the electron-
20 emitting devices are arranged in rows, each device
being connected to wirings at opposite ends, and a
modulation means is provided for them or, alternatively,
the pairs of device electrodes of the electron-emitting
devices are respectively connected to m insulated X-
25 directional wirings and n insulated Y-directional
wirings, the electron-emitting devices being arranged
in rows having a plurality of devices. With such an

1 arrangement, an electron source according to the
invention can be manufactured at low cost with a high
yield. Additionally, an electron source according to
the invention operates highly efficiently in an
5 energy saving manner so that it alleviates the load
imposed on the circuits that are peripheral to it.

According to the invention, there is also
provided an image-forming apparatus for forming images
according to input signals, said apparatus comprising
10 at least image-forming members and an electron source
according to the invention. Such an apparatus can
ensure efficient and stable emission of electrons to
be carried out in a controlled manner. If, for example,
the image-forming members are fluorescent members,
15 the image-forming apparatus may make a flat color
television set that can display high quality images
with a low energy consumption level.

20

25

1

Table 1

	Pulse width	Device current (mA)			Emission current (μ A)		
		30 μ s	100 μ s	300 μ s	30 μ s	100 μ s	300 μ s
5	Example 3 acetone	1.8	2.0	2.0	0.9	0.9	1.0
	Example 6 n-hexane	1.7	1.7	1.8	0.7	0.7	0.8
	Example 7-a n-undecane	1.4	1.4	1.5	0.5	0.6	0.6
10	Example 4 n-dodecane	2.6	2.4	2.2	1.4	1.2	1.0
	Example 7-b oil	2.9	2.5	2.2	1.7	1.4	1.1

15

20

25